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Towards The Concept Design of a Personal Air-Land-Water Vehicle

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Abstract—This paper describes the approach taken in the current research for creating the conceptual design of a personal air-land-water vehicle. The study relates to the design of a small vehicle that could operate on land, fly in air and move on the surface of water. It emphasizes on the need to understand and having skill of using 3D solid modeling for conceptual engineering design. In this paper, conceptual design refers to the initial design of parts followed by the assemblies to form components of the vehicle. SolidWorks tools have been used to support the design and development of the conceptual design. The results are summarized in the forms of structural model design, dimensions, and possibility of operation.

Keywords: Concept design, air-land-water vehicle, 3D solid modelling

I. INTRODUCTION

The vehicle to be designed is named as "Personal air-land-water vehicle" or in short "PALWaV". It is a new idea to lead in the revolution of personal transportation. The study relates to the design of a small scale vehicle that could operate on land, fly on air like helicopter and move on surface of the water like boat. Most importance for the vehicle are ability to hover specific areas of interest, serving as ideal aerial platforms for surveillances, monitoring, exploration, sport and hobby, and research development in academic field.

Although a small vehicle based on two media operation are constructed and utilized for many decades, nowadays the need for designing unmanned and autonomous small vehicle could operated in three media is a challenging job, especially to researchers with insufficient background knowledge on aerodynamics and mechanics combination of rotorcraft, car, and boat. Problems may come from various aspects such as hardware components selection, software design and anti-vibration solution. Furthermore, the commonly adopted radio-controlled (RC) hobby vehicle has strictly limited payload (less than 6 kg), which imposes much more difficulty on the design process [1].

The future requires new capabilities for new missions and this can be met by autonomous flying of such robotic vehicles. Thus, their development becomes more and more a case of not just a good flying machine, but of an intelligent robotic system set to accomplish specialized missions [2].

Several designs of small vehicles like unmanned VTOL vehicle, radio-controller (RC) vehicle already exist, having certain performance capabilities and mission applications [1, 2]. Design decisions and set specifications made at the first stages of a vehicle development designate these capabilities. A good knowledge of the antagonism and the market necessity can be a key to set design specifications for a new vehicle development.

In This study, we present to make an inventory of all feasible vehicle concepts taking into account all relevant design aspects like body structure design, part assembly, operation of the vehicle, and demonstrate the feasibility of an open part design and assemblies facility in CAD solid modeling. SolidWorks has been used to create the concept design of PALWaV.

The main objective of this paper depends on two chief. firstly is to present design concept of a new prototype personal air-land-water vehicle, suitable for a wide range of autonomous or semi-autonomous applications, including automated surveillance, target drone, environment mapping, coastal inspection, border petrol, fire detection, and traffic monitoring. Secondly is to classify the available methodologies and tools that used during concept design stage.

A starting point of this paper, the air-land-water vehicle design would be constructed and developed from the combination of personal air and land vehicle (PAL-V) was conceived by Dutchman John Bakker [3], (2004), and the WaterCar [4] is fibreglass amphibious vehicle styled design after the 2002 Convertible Camaro body style. It was designed by Dave March powered by a Subaru 2.5 Turbo WRX motor. The transmission is a Rancho Type I-4 speed manual transmission. Based on this designed, the proposed PALWaV selected design criteria are: ability manoeuvring on the air, on the land, and feasibility operate on surface of the water.

The performance characteristics of the proposed vehicle are presented at Table 1. These values also correspond to the several of mini RC helicopter, car, and boat market survey, regarding range, speed etc.

Table 1 General specification of the PALWaV

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Full length of vehicle	640 mm
Height	228 mm
Full Width	183 mm
Main rotor diameter	700 mm
Propeller diameter	254 mm
Flying weight	0.78 kg
Motor	In-runner 450 brushless motor
Maximum operating time	15 min

The rest of the paper is organized as follows: Section 2 virtual design environments, SolidWork, which is used for building up the virtual layout of PALWaV. Section 3 describes the proposed PALWaV main components, while Section 4 presents performance characteristics explanation. PALWaV frame strength evaluation is the subject of Section 4.4. Section 5 describes the future work of this research. Finally, in Section 6, we draw our concluding remarks.

II. VIRTUAL DESIGN ENVIRONMENT

The design procedure in the construction of PALWaV was mainly based on two-dimensional computer-aided-design (2D CAD) and powerful 3D design environment. We employ a powerful virtual design environment using SolidWorks, which has the following main advantages:

1. *Easy to use*: A user can be familiar with the necessary functions and instruction in a short time through learning and practicing several key examples.
2. *Powerful 2D and 3D design*: In SolidWorks, the virtual component can be modeled to be identical with the real hardware component, mainly in shape, dimension and visual properties (colour and texture). When the 3D design is finished, the corresponding 2D views will be generated at the same time for the convenience of mechanical manufacturing.
3. *Physical properties*: Each virtual component can be parameterized with necessary physical parameters such as density, modulus of elasticity, tensile strength, yield strength, thermal conductivity and weight. The center of gravity (CG) can be either calculated by SolidWorks or arbitrarily specified.
4. *Export and import utility*: Users can export SolidWork documents to a number of formats for use with other application. This utility includes descriptions and instruction for all analysis features and capabilities of the COSMOSWorks software.
5. *Animation function*: For certain components, which can move or rotate, we can emulate their motions by using an animation function.

Practical conversion systems of 2D drawings and 3D models have been developed for low and mid-range commercial CAD systems. For example, SolidWorks is a major mid-range CAD system and it can be used to generate 3D models from 2D drawings arranged in a 3D environment.

FeatureWorks is one of software modules in SolidWorks 3-D best suited for body design, main rotor components (e.g. main blade, bolts, rotor axle, hub). It contains features such as extrusions, cuts, bosses, fillets, chamfers, and surface modeling [5].

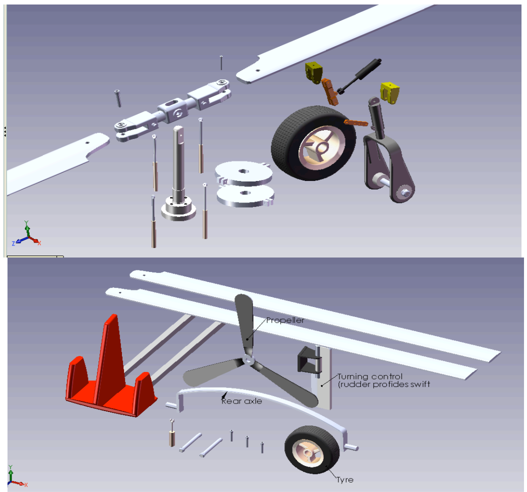


Figure 1 Parts example of the vehicle

The design parameterization conducted at both part and assembly levels. At part level, design parameterization implies creating solid features and relating dimensions among or across solid features. For example as shown in Figure 1. The part is created using dimensions standard methods and references to other geometry in the assembly. At assembly level, design parameterization involves placement constraints and relating dimensions across parts. A model assemblies example shown in Figure 2, is employed to show the effectiveness and general capabilities of the proposed system.

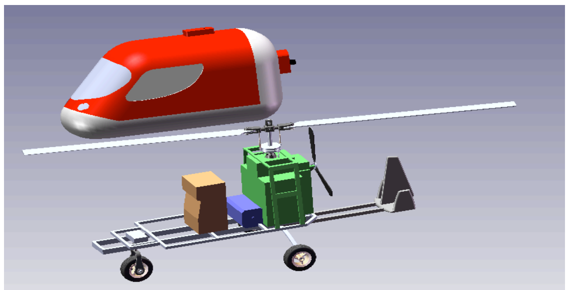


Figure 2 Example for the assemblies level

The assemblies main rotor, propeller, suspension to the body are modelled in detail on three views standard (i.e. front, right, and top view).

III. PROPOSED PALWAV MAIN COMPONENT

The basic shape of the proposed PALWaV design is shown in Figure 3. A classic rotor system with a main and propeller has been chosen for propulsion, setting initial design limits for its shape, frame design and placement of the rest of the components. Each component is indicated in Figure 4 and 5.

Construction is typically of plastic, glass-reinforced plastic, aluminium or carbon fiber. Rotor blades are typically made of wood, fibreglass or carbon fibre. Models are typically purchased in kit form from one of about a dozen popular manufacturers and take 5 to 20 hours to completely assemble.

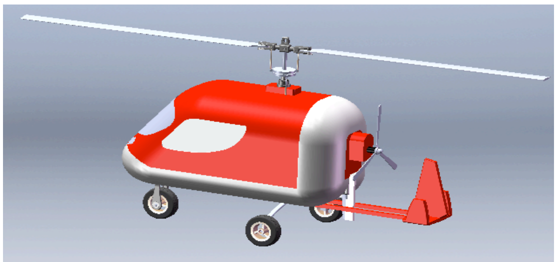


Figure 3 3-D view of the basic shape PALWaV

3.1 Main and Tail Frame

The PALWaV frame or chassis consists of two parts as shown in Figure 4, the main and the tail frame as a rudder set. This is the most important element of the vehicle design, since it dictates the vehicle's shape and it must withstand loads applied during flight, take-off and landing. Especially for the tail frame could be active during vehicle task in air manoeuvre, eventhough retractable in land and water manoeuvring.

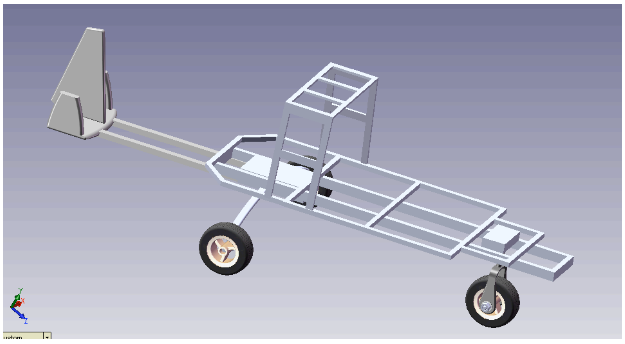


Figure 4 Main and tail frame of vehicle

3.2 Transmission system

The transmission system is placed at the centre and back of the main frame. It transfers needed power from the power motor to the main and propeller with a constant gear ratio. In case of engine failure rotors are disengaged, using a free-wheeling unit, so that the vehicle may land using autorotation.

3.3 Main Rotor

The main rotor, placed exactly above the transmission system, consists of two rotating blades with a total diameter of 700 mm, resulting in light, capable lifted the vehicle weight during flight. The two blades follow the *NACA series*, which is an asymmetrical airfoil used by the majority of such vehicle manufacturers, as resulted by the market survey on RC helicopter.

3.4 Propeller

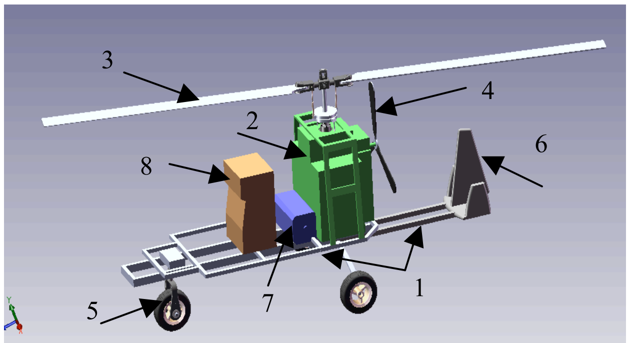
The propeller is placed at the behind of the body frame; a rotating shaft needed to transfers the movement to it. It has also two rotating blades with a total diameter of 154 mm. The diameter depends on the main rotor diameter [8] needed to produce the necessary propulsion in flight configuration that will prevent the vehicle rotation around its vertical axis. The blades follow the NACA series.

3.5 Tire and suspension

The tire and suspension set adopted from RC car tire and suspension system which needed to movement on the land manoeuvre.

3.6 Rudder

A rudder set is a device used to steer a boat, ship, submarine, hovercraft, or other conveyance that moves through a fluid (generally air or water). On an aircraft the rudder is used primarily to counter adverse yaw and p-factor and is not the primary control used to turn the airplane [7]. A rudder operates by redirecting the fluid past the hull or fuselage, thus imparting a turning or yawing motion to the craft.



1	Main and tail frame
2	Transmission system
3	Main rotor
4	Propeller
5	Tire and suspension
6	Rudder
7	Motor
8	Payload

Figure 5 PALWaV components

In basic form, a rudder is a flat plane or sheet of material attached with hinges to the craft's stern, tail or after end. Often rudders are shaped so as to minimize hydrodynamic or aerodynamic drag.

3.7 Engine

The engine is using the powerful electric system, placed horizontally at the front of the vehicle frame, based on four anti-vibration mounts. The main frame dimensions are set in such a way to allow for and accommodate several power electric types with different horsepower depending on applications.

Recent advancements in battery technology are making electric flying more feasible in terms of flying time. Lithium Polymer (LiPo) batteries are able to provide the high current required for high performance aerobatics while still remaining very light. Typical flight times are 4-15 minutes depending on the flying style and battery capacity.

3.8 Centre of Gravity

The position of the PALWaV center of gravity is very important for flying. The type of propulsion used is an important factor of defining the best C.G. position. In the proposed design, the ideal placement is exactly on the axis of rotation of the main rotor [6]. In this way, the frame remains horizontal during hovering; controlling and manoeuvring the vehicle becomes easier.

3.9 Payload

Payload, in most of cases, corresponds to ability in assuming or completing a mission. Thus it is of importance for such a vehicle to carry as much as possible payload, as also to host it on the fuselage in a way that especially electronic equipment can function without being interfered by vibrations.

The 100 g of payload positioned close to vehicle centre of gravity, as shown in Figure 5. This placement provides the needed flexibility required, so that multiple kinds of equipment can be used easily. This includes light camera, and any kind of additional electronic devises required for specialized missions. For all these, a special mount functioning as an isolation mechanism will be developed. The base must isolate vibrations interfering with electronics. This can be addressed only after ground and flight tests are conducted and vibration measurements are available.

3.10 Electronic Equipment

The basic electronic systems placed on the vehicle consist of a gyro and a remote/autonomous control module. Depending on the mission and application such equipment may be modified. Electrically powered models utilize mechanical or electronic speed control units to adjust the amount of power delivered to the electric motor. The power delivered is proportional to the amount of throttle called for by the transmitter - the more you pull the trigger, the faster it goes. Based on the design criteria, basic concept for PALWaV must be compiled with satisfactory condition motion in different media operation as shown in Table 2.

Table 2 Design criteria for different media operation

Components	Sufficient condition		
	on air	**on land**	**on water**
Main rotor	Active	Inactive/ Foldable	Inactive
Propeller 1	Active	Inactive	Inactive
Propeller 2	Inactive	Inactive	Active
Rudder	Active	Inactive/ Retractable	Active/ retractable
Tire/ Suspension	Active	Active	Inactive/ Foldable

IV. PERFORMANCE CHARACTERISTICS

From the market survey, certain performance specifications have been set as satisfactory skills for a new vehicle. The performance characteristics for the proposed prototype vehicle are identified and evaluated at this section, revealing the calculations needed for the values already shown. Capabilities evaluation is done in terms of weight capability during hovering, maximum speed, ceiling and endurance; most critical parameters affecting such capabilities are available engine power, maximum weight, rotor design and special aerodynamic factors [9, 10, 11].

The available engine power is the essential effecting parameter of the calculations, including three terms:

a. The power installation available for the PALWaV for used on air, land, and water is In-runner 450 brushless motor types.

b. The required main rotor power, needed to produce the thrust moving the helicopter. This power is computed by the following equation

$$P_{Main\ Rotor} = P_{Parasite} + P_{Induced} + P_{Profile}$$

where:

$P_{Parasite}$: the parasite power required to overcome the drag force, depending on the vehicle's shape, which is developed during the forward motion. The parasite drag can be approximated by adding the incremental equivalent flat-plate area of each of the components of the vehicle. The equivalent flat-plate area *f*, is simply drag divided by dynamic pressure. It is the frontal area of a flat plate with a drag coefficient of 1, which has the same drag as the object whose drag is being estimated. It is estimated by adding up the drag of various components based in theory [7, 12].

$P_{Induced}$: the induced power required to produce the needed air wake passing downwards through the rotor, resulting in thrust.

$P_{Profile}$: the profile power required to overcome the friction drag of the individual blade elements, caused by the rotation of the main rotor and depending on blade's shape.

c. The required propeller power, needed to compensate the main-rotor torque in hover. This term is calculated taking into account the propeller thrust, the air density at specific altitude, the area defined by the rotation of the propeller blades, the main-rotor torque and the distance between tail and main-rotor axis of rotation.

The knowledge of all the parameters affecting the terms presented before, leads us to the estimation of the specific performance characteristics that follow.

4.1 Weight capability during hovering, landing and on surface of water

Altitude may alter the weight that the vehicle may hold while hovering above a specified ground point. If the vehicle is positioned close to the ground, less power is needed for hovering; this state is called 'In Ground Effect' (IGE). If the vehicle is hovering far away from the ground, more power is required; this state is called 'Out of Ground Effect' (OGE). It is observed that (given the 450 brushless motor) the proposed PALWaV vehicle may hover with a maximum weight of 831 g (780 g) at IGE (OGE), respectively.

4.2 Forward Speed

The maximum forward speed was found based on the available power commonly used by several remote controller vehicles. The value shown corresponds to power needed to move the main and tail rotors so that the vehicle may fly forward with a specific speed.

Calculations have considered factors related to aerodynamic drag losses due to the shape of the vehicle and the rotor blades, and power losses for secondary systems. Since the power is 3800 KV and 11.1V 2200mAh Li-Po battery, the maximum forward speed is up to 70, 60, 48 km/h for on air, land, water operation respectively.

4.3 Endurance

As previously stated, endurance corresponds to flying time. According to the capacity of power and battery selected, the endurance value for the proposed vehicle is [15] at 15 min. Given the market analysis and technical comparison already presented at Section 3.7 it may be postulated that the values obtained are quite satisfactory and meet set requirements. The computed vehicle capabilities are as presented in Table 1 at the introduction.

4.4 Frame Strength Evaluation

Loads PALWaV must withstand during operation are crucial for their lifetime. It is therefore crucial to validate whether a designed vehicle is capable of operating safely by minimizing the possibility of material failures. To accomplish this, specific steps are followed, as illustrated in Figure 6. The frame is the most important component that needs be evaluated; the frame must not fail as long as the vehicle functions within its design and operational limits. Once the vehicle frame design phase is completed the steps shown in Figure 6 follow. This section, except of the use for validation of the fuselage strength, is the way for weight distribution, material selection and finally optimization of the frame design characteristics.

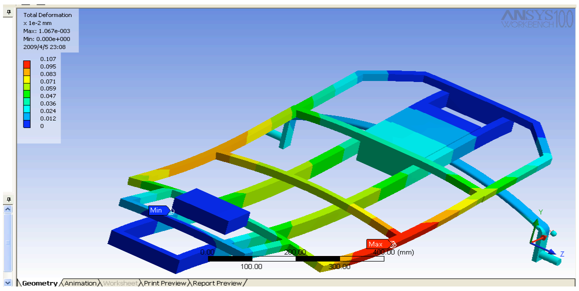


Figure 6 Basic concept analyze frame strength

At first, the frame is subjected to a virtual crash test under specific conditions of vehicle construction [12, 13, 14]. Results evaluation follows, examining frame areas where high stresses are shown, as well as examining total frame reaction during time of impact. If stresses exceed material yield stress limit, plastic deformations occur. A redesign phase follows, where specific frame components are modified, and the sequence starts again performing a new crash test until stresses developed are lower than the material yield stress limit. When this is the case, the design meets requirements and the evaluation sequence terminates.

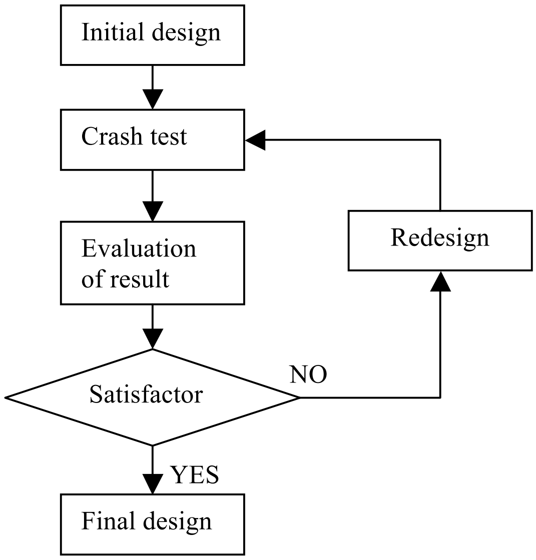


Figure 7 Iterative design process for crashworthiness

For the virtual crash test and calculation of stresses developed, the ANSYS specialized FEA program is used [2, 16]. Once the geometry model is created, the lines, surfaces and solids are meshed (discretized) to create the beam, shell or solid elements. The type of elements used, depend on the type of the problem to be solved and on the design of the structure.

V. Future Work

Future flight tests are planned to improve performance further and produce desirable handling quality rating (HQR). The main focus will be on the design of control laws and stability which are sufficiently fast for desirable performance, yet produce less active control signals in order to improve ride quality.

VI. Conclusion

This paper has successfully discussed the fundamental integrated steps for a conceptual design system emphasizing on the conceptual design of PALWaV. SolidWorks has been used to support the solid modeling and design parameterization concept. Structural model design and characteristic of PALWaV have to be established first before the control, stability, and performance of the vehicle could be analyzed. For this purpose, numerical analysis and experimental method will be employed to ensure safe PALWaV operation in the real environment.

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